SIMULATION OF MILITARY CONFLICT

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1. INTRODUCTION

The field of simulation in support of military decisions has expanded enormously in the past few years. It is difficult to pin down the precise extent of activity in this area, but something of the order of 200–300 major simulation projects have been carried out during the past three years in the U. S. alone. The simulations range all the way from a very detailed representation of a full-scale global aerospace war down to, e.g., a computation of the damage inflicted on a static battalion of troops by a group of tactical aircraft dropping conventional high-explosive bombs.

There is no doubt that the major cause for this explosion in the use of simulations has been the development of high-speed electronic computers. The digital computer is ideally suited to carry out the detailed mass of bookkeeping and perform the manifold calculations required by an extensive simulation. But also important has been the impact of

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rapidly changing technology on the nature of military decisions. The requirement to prepare for potential conflicts with weapons of a radically new sort, where previous experience gives little guidance, imposed the necessity for developing a substitute for experience; and simulation is precisely a technique for creating synthetic experience.

2. TAXONOMY

To get some perspective on this rapidly expanding field, it is useful to classify simulations according to a simple triple of characteristics:

1. Size: number of elements or amount of detail.
2. Formalization: extent to which rules are explicit and complete.
3. Analyticity: extent to which preferred or optimal "solutions" are computed.

This classification scheme is illustrated in Fig. 1. For purposes of discussion, a simple division into small, medium, and large is made on each axis, and some representative simulations are noted in a number of the boxes.

Down toward the origin, we have informal "quick looks." "Back-of-the-Envelope" is as good a characterization as any. The region includes corridor chats and rough "estimates." About the most that can be said concerning this region is that a significant number of military decisions are made on the basis of such "analyses," and some attention on the part of the analysis community to quick-look techniques would not be wasted.

Moving along the low formalization level there are many relatively unstructured exercises illustrated by crisis games and political games. This kind of exercise is no longer popular for pure military conflict although it is still occasionally used. In the exercises a loose structure

is imposed. There may be teams representing various nations and a control team to monitor moves and furnish the environment. Usually the rules are not explicitly stated and the simulation is afforded by role-playing. The technique is usually applied to international situations with strong military overtones such as the Berlin crisis. It is difficult to give a sharp estimate of the "size" of such simulations, since the elements that can be taken into account are essentially unbounded and the only constraints are the participation time of the players.

Moving up on the formalization scale, we have simulations where part of the exercise is determined by explicit rules, but another part—usually the planning or decision-making part—is conducted by human role-playing.

STRAW was an illustrative industrial bombing game, played on a board with chips to represent bombers, and miniature replicas of factories for industrial targets. It was played like Kriegspiel, with players receiving partial information during the course of a game. It was not intended as a serious tool of analysis, but as a training device and pilot model for a more ambitious simulation.

SWAP is a more extensive game somewhat in the STRAW spirit, but with a more realistic set of inputs. It has the extra feature that initial plays of the game consist in buying additional forces over time; and the game evaluates the augmented force structures as well as force employment.

COW is an international relations game. The economies and military establishments are constrained by precise models, but investment policy and military actions are player decisions. Political factors are simulated by informal interactions among the players and a control team.

In the larger semi-formalized class are many traditional map exercises, of which SIERRA is a good example. It was a detailed limited war game, with some care being taken to include political as well as purely military factors in determining the course of a conflict. The political factors were not modelled explicitly but were assessed by a control team.

On the next level, we have simulations where plans and policy are included in the formal model. TAGS is a small Theatre Air War Game which describes the conflict in terms of a set of differential equations determining the motion of a front line. A plan is expressed as an allocation over time of the air effort to several missions: ground support, air defense, counter air (strikes on airfields) interdiction, and reconnaissance. The model is coded for a computer and can be played with a variety of initial conditions and plans.

STAGE may be thought of as the exemplar of a very large computer war game. It follows in great geographic detail the movements of bombers and missile across the globe, and plays through the intricate interaction of offensive and defensive forces. Plans consist of highly specific schedules

of weapon employment. The routine can take many hours on a high-speed computer to produce one Monte Carlo sample of two days of nuclear war.

TEMPER* is a computerized model of international behavior. Each country or country bloc is represented by an economic, a military and a political model. The routine is fully automatic. Associated with each country is a decision routine which manages the economic, military and political submodels as well as interactions with other nations. Starting from a set of initial conditions the model will generate a synthetic history over a period of a decade or so. The models for any country are highly aggregated, but when ten to twenty countries are simulated, the number of elements becomes very large.

The purpose of this hasty sampling is not to give a Cook's tour of military simulations; the field is much too extensive for comprehensive survey in the short time I have. Rather, the purpose is to indicate that on the zero level of analyticity practically all kinds of simulation structures and techniques have been applied to military problems. The second purpose is to point out that as you move out of the zero-analyticity plane, the space becomes practically empty. I have drawn a dotted line slanting across the region to indicate that there is a close coupling between degree of formalization and the degree to which preferred courses of

*Developed by Clark Abt at the Raytheon Corporation.

action can be computed. In order to invoke a formal optimizing or meliorating procedure, it is necessary to have an explicit model. Of course, even with informal simulations it is possible to do something—namely, try a number of cases—and thus the line cuts off only at zero.

3. THE HYPOTHETICO-DUDUCTIVE APPROACH

Most military simulations proceed by the case study method. A run represents a single potential conflict. The method of employment—ideally—is experimental. A few cases are run, hypotheses concerning improved policies or weapons are generated by that still mysterious process called "insight" and these hypotheses are tested by further runs. This process is relatively effective in areas where the simulation can be tested against operating experience—e.g., in areas of logistics, inventory policy, or maintenance. In areas where testing is virtually impossible, e.g., in the fields of nuclear war or major conventional conflicts, the hypothetico-duductive technique can be—and is—still employed. But the range of uncertainties connected with the results is so great that sharp conclusions are rare.

4. THE FOUR UNCERTAINTIES

The military analyst faced with the problem of evaluating weapon systems and weapons employment, particularly for research and development decisions, is plagued with four uncertainties. These can be called:

1. Stochastic.
2. Epistemic.
3. Strategic.
4. Axiological.

Stochastic uncertainties arise where events are probabilistic, rather than strictly determined. Epistemic uncertainties arise where we simply don't have enough information to make a prediction. Economists have called this type of uncertainty "risk." Strategic uncertainty occurs if two or more independent decisionmakers can influence the outcome—as is certainly the case with military conflict. Finally, axiological uncertainty arises when there is no well-defined payoff or criterion to form the basis of evaluation. Stochastic uncertainty can be dealt with by expected value models—which are really a form of strictly determined model where fractions or averages replace exact values of parameters—or by Monte Carlo models where chance (or pseudo-chance) events determine the outcomes of probabilistic activities in the model.

Epistemic uncertainty has been less thoroughly explored. The theory of decisionmaking with incomplete information is still a controversial subject. In the case of simulation

the usual approach is so-called sensitivity analysis where a range of possible values for the incompletely known parameters is examined.

The type of analysis that is most appropriate for dealing with uncertainties concerning ememy strategy is the theory of games. The small theatre air war game, TAGS, has been formulated—with some simplifications—as an analytic game and a solution found. This is the game TAW located in the upper left hand box in Fig. 1. A few other small games with significant military content have been solved primarily in the areas of bomber and ballistic missile defense.

Finally, axiological uncertainty is often by-passed in simulation studies by using what has been called the Williams payoff (after the late John Williams). A number of indices—damage, casualties, forces remaining, etc.—are computed and reported. The decisionmaker observes the outcomes (as defined by these indices) of various potential conflicts and "makes up his feelings" about them.

In general, for extensive simulations, none of the methods of handling the four uncertainties are satisfactory. The expected value method does not produce a true expected outcome, and gives no indication of the variance. The Monte Carlo technique for dealing with stochastic uncertainty, and sensitivity analysis for dealing with epistimic uncertainty have the major drawback that they require many runs to give

an adequate coverage of the range of uncertainties. With extensive simulations the computation time required to make these many runs is prohibitive.

The theory of games has afforded little more than conceptual guidance for the large simulations. These simulations cannot be formulated as explicit equations, and even if they could, are so complex that finding a solution would be unlikely. Furthermore, most military conflicts are nonzero-sum and the theory of nonzero-sum games is still in an unsatisfactory state.

The Williams payoff, from the present point of view, is a mild form of giving up.

5. FAMILIES OF MODELS

It can be concluded from the previous remarks that one of the greatest challanges facing the operations research community is the development of more powerful techniques for dealing with complex simulations.

In order to make significant improvements, it is not necessary to go to the full optimization procedures of game theory or linear or dynamic programming. Suboptimization over less critical variables is a simpler and probably more feasible step. This was the route followed in the model STRAP, a nuclear war planning model. The general idea in STRAP is that an experienced planner submits a summary of a war-plan, that is, a general allocations of weapons to targets. The routine then "fleshes-out" this summary by suboptimizations on specific flight paths for bombers, refueling, attacks on defenses, and so on.

However, STRAP is still too slow to be useful, for example, in sensitivity studies on poorly known parameters, or for examining the effect of enemy strategy. One technique to deal with this problem is the use of a family of models on different levels of generality where small, highly aggregated models can be used to compute optimal "solutions," and more detailed models can be used to check the feasibility of solutions and introduce operational realism. We have built such a family of models at RAND. The small, capping model is a two-sided war game that runs in about 1/50 of a

second on the IBM 7040-44. It is thus feasible to explore a wide range of possible wars. The intermediate model is STRIP, which appears in Fig. 1 in the middle box on the top level. It has the function of unpacking the results of the capping model and grossly testing their feasibility. The detailed model is STRAP, which primarily has the function of feasibility checking and introducing specific operational constraints.

The family of models concept appears to be applicable to many types of computations other than operations planning. For example it is suitable for evaluation of future force structures, and looks useful for long-range policy planning in both military and nonmilitary areas.

However, it must be recognized that the scheme is very incompletely defined. It would be desirable to have fully analytic models at the top. At present we use the technique of generating a large sample of strageties for each side and computing the sample matrix of outcomes. This sample matrix can then be scanned (by the computer) for dominance, and for equilibrium points. There are, at present, no good aggregation or disaggregation rules for integrating the set of models in a formal fashion. And it would be desirable to have theoretically founded suboptimization techniques in the intermediate and lower levels.

6. TOWARD THEORY

At present, the construction of a simulation is almost entirely an intuitive art. A step forward has been taken by the development of the various simulation languages. A number of these have been produced in the last several years—Simscript, GPSS, GASP, Militran, among others. These computer languages furnish the practitioner with a pre-designed structure for simulations—a sort of framework on which the simulation builder can hang the specifics of his problem. These structures have afforded some insight into the nature of simulations. However, they have moved in the direction of design tools, not of theoretical constructs for the analysis of simulation.

Most military simulations can be defined in terms of the structure outlined in Fig. 2. Elements are the things—bombers, missiles, targets, etc.—with which the simulation deals. These will usually be represented by lists. Attributes are the properties or characteristics of the things—bomb capacity and range of bombers, accuracy of missiles, etc. They can be fixed—location of an airfield—or variable—operational status of the field. The attributes will be represented by tables or be attached to the lists of elements. Activities are the kinds of events or processes that can occur during the conflict—take-off of bombers, launch of missiles, damage to targets, etc. Activities are usually expressed by computational routines determining how the

variable attributes of things change depending on the situation. <u>Plans</u> are the policies and doctrines that steer the course of the conflict. These can be represented by explicit schedules of events, or by rules (in which case they are frequently incorporated into activities). <u>Time</u> is the basic structural element of military simulations and determines the organization of the compute routine—the "master program." It can be handled by one of two devices, the interval technique, or the event technique. In the interval technique, time is divided into small, usually equal, segments and the routine proceeds interval by interval. In the event technique, a list of all potential events is pre-computed on the basis of plans and resultant activities. The computation then proceeds by taking up each event in turn. The event list must be edited from time to time since some events may preclude others, and unscheduled events may arise during the course of the run.

The foregoing structure can be summarized by saying a simulation consists of a state vector S, the list of things and their attributes, and a transformation T that operates on the state vector to produce a state at a later time, (Fig. 3). T represents both activities and plans, as indicated in Fig. 3b. And plans may consist of a set, with a separate plan for each of several independent decisionmakers, as in Fig. 3c.

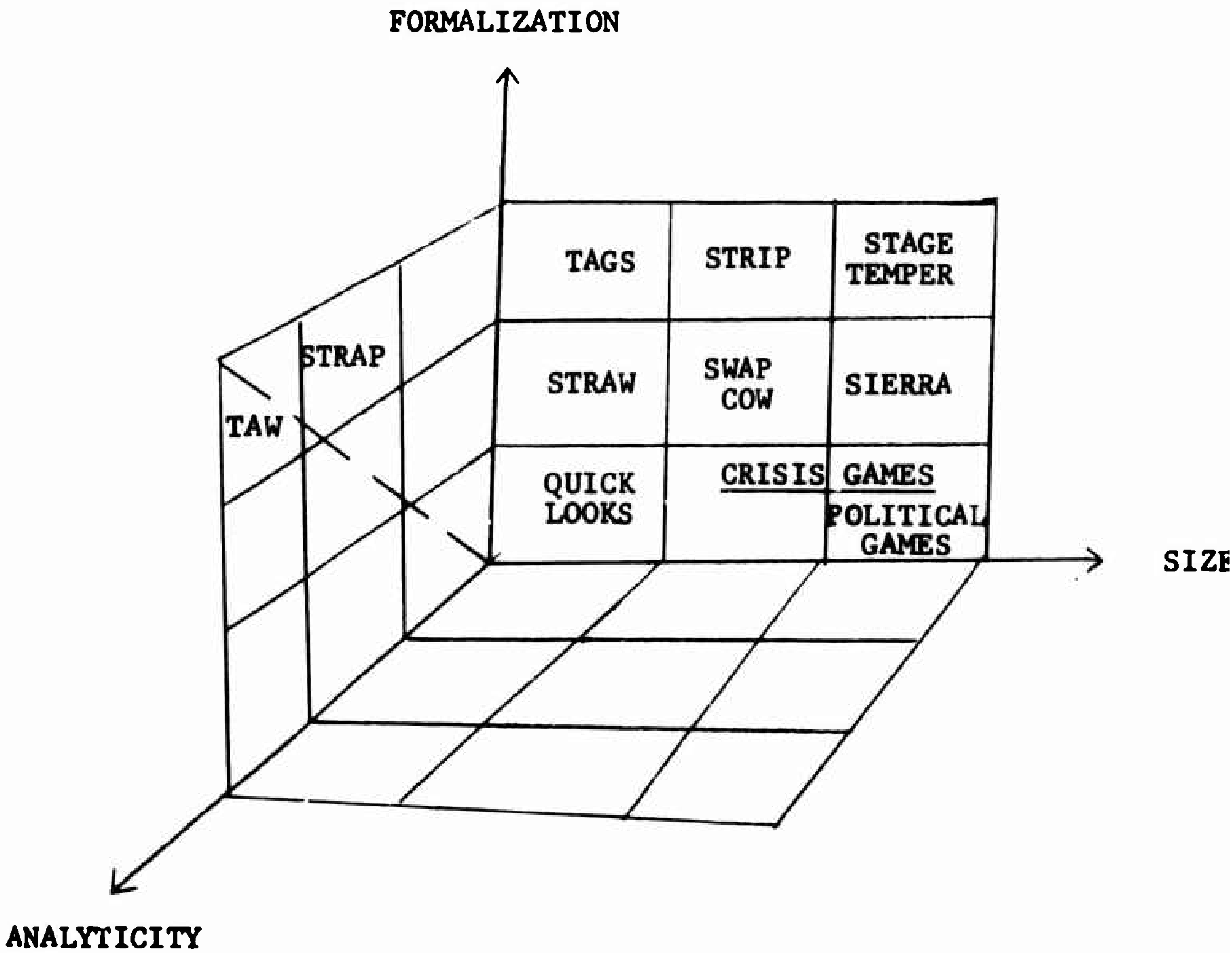
Cast in this form, a simulation is a dynamic process, which may also be stochastic, if the model is of the Monte Carlo type. However, most military simulations have little in common with the kind of model dealt with by the mathematical theory of stochastic processes. War is a highly transient phenomenon, and the transformation T cannot be expressed as a simple array of probabilities.

The present form of simulation languages tends to obscure the difference between plans and activities. In general, the goal of operations research is not merely to describe the world, but to discover preferred courses of action. Accurate description is, of course, a prerequisite for action selection, but is not sufficient. This formal deficiency in the simulation languages may not be critical. It is probably feasible to modify the languages so that plans appear as distinguishable items.

The family of models structure highlights some additional gaps in the theoretical understanding of simulation models. For example, in aggregation techniques, more or less traditional methods of averaging and index number construction are adequate for aggregating elements, attributes, and to some extent, plans. But there are no general techniques for aggregating activities. Here the hypothetico-deductive method still appears to be the best we have. That is, you "invent" small models and test them against more extensive simulations.

In the reverse direction, i.e., in the direction of disaggregation, the situation is more complex. If an optimizing procedure has been employed on the higher level, then suboptimization is required over the set of aggregated elements. In the experimental family of models dealing with central nuclear war, the suboptimization rules were devised mainly on the basis of what is called experience and judgment. They were then tested by reaggregating the results of a series of runs and comparison with the predicted results of the smaller model. In this particular case, the rules worked satisfactorily, although there is a hint of bootstrapping involved. It is clearly desirable to have a firmer approach.

The family of models does represent an "experimental" situation in which some of the problems of constructing a theory of simulation can be approached. This application is useful for questions other than those of aggregation. One of the severe limitations on the use of simulation in the area of central nuclear was has been the difficulty of devising a suitable payoff. In the context of a family of models, it is possible to formulate a well-defined payoff with the assurance that the effects of employing that payoff will be checked against more detailed analyses.



SIMULATION "SPACE"

Fig. 1

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1. Elements
2. Attributes
3. Activities
4. Plans
5. Time structure

STRUCTURE OF SIMULATION

Fig. 2

a. $T \cdot S_t \rightarrow S_{t+\Delta}$

b. $T = T(S, P, t)$

c. $P = (P_1, P_2, \ldots, P_n)$

T: a transformation

S: a state vector

P: plans

P_i: plan of an independent decisionmaker.

ABSTRACT STRUCTURE OF A SIMULATION

Fig. 3